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ENHANCED BACKSCATTERING FROM ROUGH SURFACES

FINAL REPORT

Prepared for:

U.S. ARMY RESEARCH OFFICE
Research Triangle Park, NC   27709-2211

**SURFACE OPTICS
CORPORATION**

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13. ABSTRACT (Maximum 200 words)

We have been conducting a combined theoretical and experimental research program in the field of enhanced backscattering from randomly rough metal and dielectric surfaces. The principal goal of this study is to improve our understanding of the mechanism responsible for the enhanced backscattering pehnomenon. At the same time, the results we obtained will apply to remote sensing and radar clutter research.

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1.0 STATEMENT

Surface Optics Corporation (SOC), in association with U.C. Irvine and CICESE, has been conducting a combined theoretical and experimental research program in the field of enhanced backscattering from randomly rough metal and dielectric surfaces. The investigation centers on the subject matter of Enhanced Backscattering manifested as a narrow peak in the angular distribution of the intensity of diffusely scattered light in the retroreflection direction for any angle of incidence on characterized surfaces which were fabricated by a computer driven laser scanner with controlled statistics.

Although there has been a significant increase of interest in enhanced backscattering phenomena over the last couple of years,[1-5] much more has been accomplished during this contracting period. We have shown the specular enhancement in both reflection and transmission.[6] We have measured the enhanced transmission.[7] We have exhibited the enhanced backscattering from smooth metal surfaces,[8] and the enhanced backscattering from a rough dielectric film on a glass substrate when the light illuminates the rough surface from the dielectric side, entering from the glass substrate.[8] We have also predicted the enhanced backscattering from deterministic quasi-periodic surfaces, and from random rough surfaces nearly perpendicular to a mirror.[9]

We have initiated research on the speckle correlation in the double passage configuration and the interaction of two coherent beams at a random symmetric surface.[10, 11]

Recently we have measured the giant enhanced backscattering, where the ratio of the height of the enhanced backscattering peak to that of its background is much larger than a factor of two predicted theoretically. For technology transfer, we have also designed, fabricated and delivered a monostatic bidirectional reflectometer.[12]

The principal goal of this study is to improve our understanding of the mechanism responsible for the enhanced backscattering phenomenon. At the same time, the results we have obtained will apply to remote sensing for scatter and backscatter from various surfaces, terrains and backgrounds, high-intensity laser propagation, and radar clutter research.

2.0 SUMMARY OF THE PROBLEM STUDIED

Recently (during the period from 1 October 1989 to 30 September 1992) under U.S. Army Research Office Grant DAAL03-89-C-0036, we have been investigating The enhanced backscattering from rough surfaces. The advances in our understanding of enhanced backscattering from rough surfaces are summarized as follows.

2.1 Specular Enhancement

Coherent effects in the interaction of light with random surfaces with symmetry have recently been investigated.[6] There are two such effects. The first is the presence of a peak in the specular direction in the contribution to the mean differential reflection coefficient from the incoherent component of the scattered light. This effect has been called specular enhancement. The second is the presence of a peak in the forward direction in the contribution to the mean differential transmission coefficient from the incoherent component of the transmitted light. This effect has been called specular refraction. Both of these effects can be detected only for symmetric random surfaces rough enough to extinguish the coherent component of the reflected or transmitted light. Symmetric surfaces do not, in general, occur naturally, so they had to be fabricated. The symmetric surfaces were fabricated by randomly exposing photoresist-coated plates under computer control, in the manner described in Reference 13. Since the angular width of the enhancement is comparable to the speckle size, which is much smaller than the aperture size in front of the detector, we have to fabricate symmetric surfaces that are composed of several (~ 150) segments, each with a center of symmetry, so that the main angular width is widened and a good estimate of the spatial ensemble average is obtained.

Specular enhancement in both reflection and transmission has been observed experimentally and compared with a theory based on the Kirchhoff single scattering approximation. For symmetrical random surfaces, the enhanced mean intensity due to the coherent effect was measured. For symmetric surfaces with height steps, the predicted reduction in the mean intensity was also found. These experiments show that the average diffuse intensity from randomly rough surfaces with even symmetry can be enhanced or reduced in the specular direction due to the constructive or destructive interference between correlated pairs of scatterers.

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2.2   Enhanced Backscattering

We have fabricated one- and two-dimensional random surfaces using a combination of the scanning and speckle techniques. These surfaces have statistical properties that are approximately Gaussian in some cases, but in others can be very non-Gaussian. However, in all cases their statistical properties are well defined. We have conducted an experimental study of light scattering from a gold-coated quasi- one-dimensional random surface (Sample No. 12101) with rms height $\sigma \cong 1.5$ μm, and a correlation length $a \cong 4.0$ μm. The enhanced backscattering from such a fabricated one-dimensional random surface coated with gold was measured at $\lambda = 0.6328$ μm and compared with the numerical simulations.[14]

We have conducted experimental studies of light scattering from a two-dimensional dielectric surface. The surface is a glass substrate coated with photoresist, fabricated with the speckle technique with an rms height $\sigma \cong 0.44$ μm and a correlation length $a \cong 2.3$ μm. There is no enhanced backscattering measured at $\lambda = 0.6328$ μm when the light is incident on the front photoresist surface (see Figure 1 (a)). But there is evident enhanced backscattering measured when the light is incident on the back glass substrate (see Figure 1 (b)).

To understand better the mechanism that is responsible for this peak, we have carried out numerical calculations for light scattering from a one-dimensional random rough surface. Our results show that the absence of the enhanced backscattering peak in the former case is due to the glass substrate, while in the latter case, it is due to the higher reflectivity of the system. The multiple scattering at the rough surface gives rise to the peak.[8]

2.3   Enhanced Transmission

It was recently shown that the angular distribution of the intensity of the incoherent component of p-polarized light transmitted through a thin metal film surrounded by vacuum, whose illuminated surface is randomly rough while the back surface is planar, displays a well-defined peak in the antispecular direction in transmission.[6, 15] It is believed that the physical origin of this effect is the scattering, by the surface roughness, of the surface polaritons in the film excited, through the roughness, by the incident light. The coherent interference of a doubly scattered light/surface polariton path with its time-reversed partner gives the dominant contribution to this enhanced transmission.

The experimental investigation of this effect used a He-Ne laser with $\lambda = 0.6328$ μm. Measurements of the angular scatter of the transmitted light from gold ($\sigma \cong 106$Å, $a \cong 1484$Å) and silver ($\sigma \cong 118$Å, $a \cong 1200$Å) coated two-dimensional surfaces have been made. An enhancement in

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2-D DIELECTRIC SURFACE

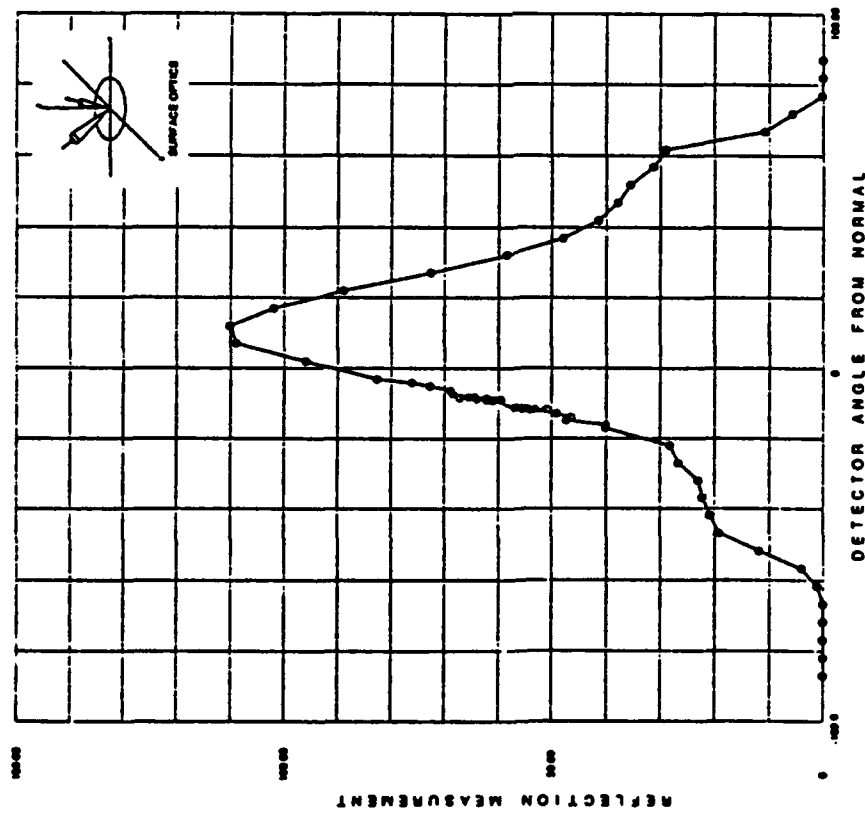Figure 1 (b). Same as (a), Except the Incident Beam is on the Glass Substrate.

Figure 1 (a). Relative Reflection Measurement for a Two-Dimensional Dielectric Surface for Angle of Incidence = 10° and P-P Scattering. The Laser is Incident on the Photoresist Surface with $\lambda = 0.6328$, $\sigma = 0.44$ μm, and $a = 2.3$ μm.
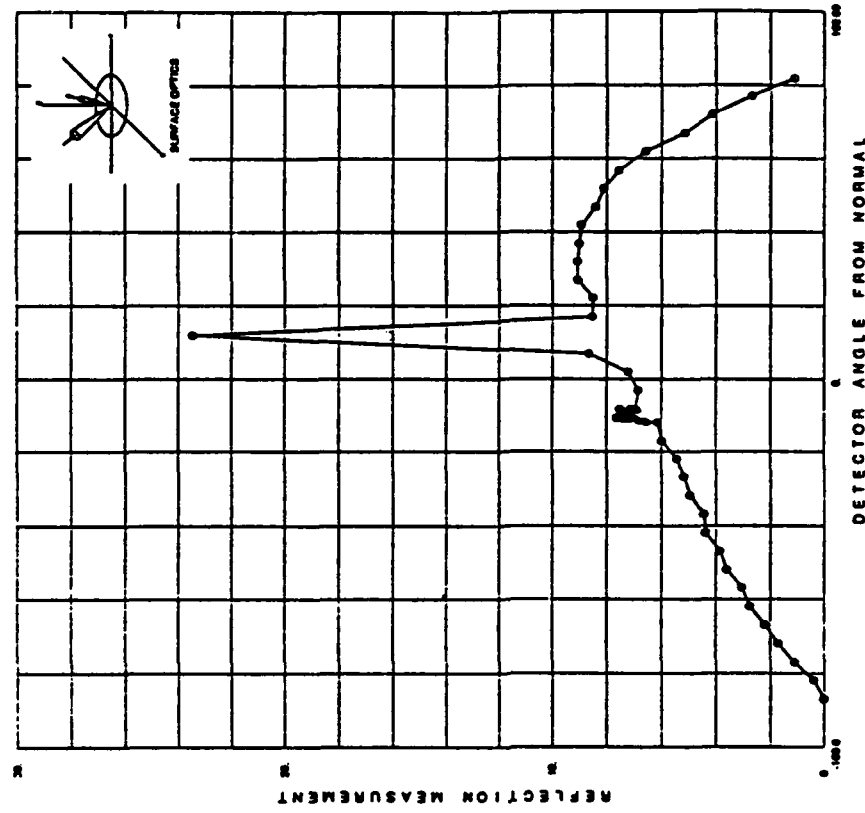
4

the diffusely transmitted intensity is found in the anti-specular reflection direction. The experimental results were compared with the theory.[7]

2.4   Enhanced Backscattering from Deterministic Quasi-periodic Surfaces

It is normally assumed that in order to have enhanced backscattering one needs some randomness on the surface. We have shown by means of rigorous computer simulations that it is possible to observe enhanced backscattering from some kinds of deterministic surfaces. One of the surface profiles that we have considered is given by the equation

$$\zeta(x) = \zeta_0 \cos\left[\frac{2\pi}{T}(x + bx^3)\right] \quad .$$ (1)

A profile calculated from this expression with $T = 25$ μm, $\zeta_0 = 1$ μm, and $b = 0.0001$ μm^{-2} is shown in Figure 2 (a). The surface is $L = 300$ μm long. The Differential Reflection Coefficient, calculated for an angle of incidence $\theta_0 = 5°$ is shown in Figure 2 (b). In each case, well pronounced peaks are observed in or around the backscattering direction. We have found that this is the case for any angle of incidence, at least in the range of $|\theta_0| < 30°$.

2.5   Interaction of Two Coherent Beams at a Random Symmetric Surface

We have studied the interaction of two coherent optical beams at a random symmetric surface.[11] By means of experiments, computer simulations, and an analysis based on the thin phase screen model, we have given conclusive evidence of the presence of coherent effects due to this interaction. We have found that, in addition to the two sharp peaks corresponding to the enhancements in the specular directions, there is a third peak, whose height depends on the relative phase of the two incident beams. The pronounced sensitivity of this third peak to the phase difference between the two incident beams is strong evidence for the origin of this phenomenon in the interference between the two scattered fields. It is also interesting to note that this third peak is not present in the results obtained from pure double scattering processes.

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Height (microns)

1.5
1.0
0.5
0.0
-0.5
-1.0
-1.5

-200 -150 -100 -50 0 50 100 150 200

Position (microns)

Slope

3
2
1
0
-1
-2
-3

-200 -150 -100 -50 0 50 100 150 200

Position (microns)
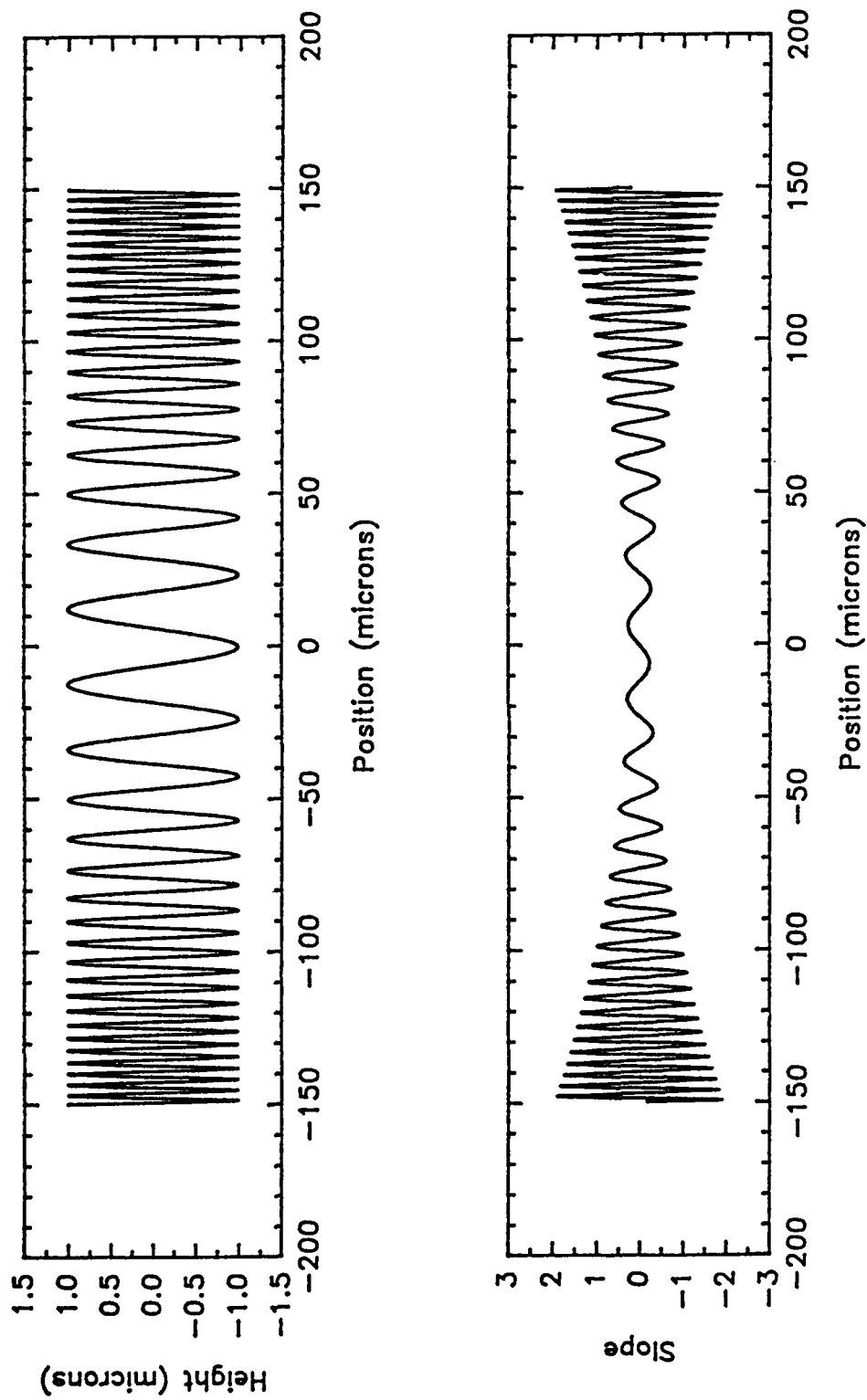
Figure 2 (a). Surface Profile and Slope with the Following Parameters:

$$\zeta(x) = -\zeta_0 \cos\left[\frac{2\pi}{T}(x + bx^3)\right]$$

$T = 25$ μm, $\lambda = 0.6328$ μm, $\zeta_0 = 1$ μm, $b = 0.0001$ μm^{-3},
$-L/2 < x < L/2$, $L = 300$ μm.

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Figure 2 (b). The DRC for the Perfectly Conducting Surface whose Profile is shown in Figure 2 (a) when the Angle of Incidence is $\theta_0 = 5°$. The wavelength of the light is $\lambda = 0.6328$ µm.

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From our results we conclude that the two peaks due to specular enhancements, as well as the third peak between them, are primarily due to single scattering. However, the physical origin of the peak due to the interaction between the two beams seems to be different.

The analysis based on the thin phase screen approximation provides a qualitative explanation for the experimental results, displays explicitly the origins of the interference phenomena, and also shows good overall agreement with the rigorous computer simulations for cases in which multiple scattering is negligible.

2.6 Enhanced Backscattering from a Random Rough Surface Nearly Perpendicular to a Mirror

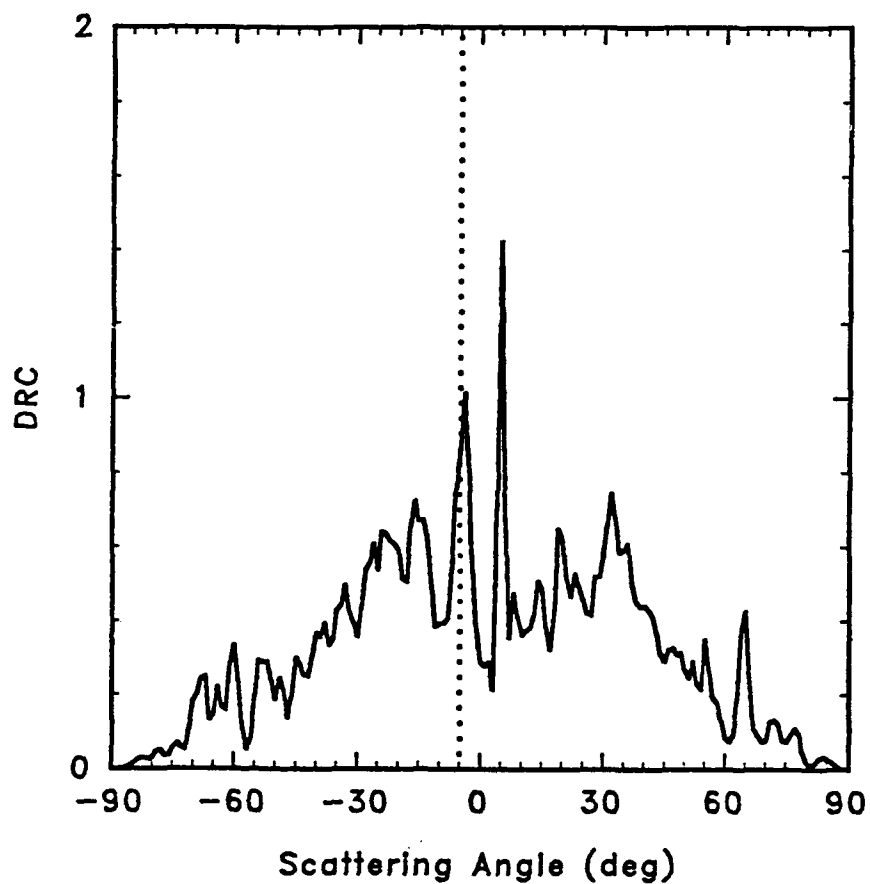Measurements of light scattering from a random metallic surface perpendicular to a mirror show the enhancement of the intensity of the scattered light in the backscattering direction. The situation has some parallels to that of scattering from a surface with an even profile. With an approach based on the thin phase screen model we have shown that this scattering system exhibits the phenomenon of enhanced backscattering. It has been found that the enhancement is due solely to the constructive interference between counter propagating reciprocal double scattering paths.[9]

2.7 Speckle Correlations in the Double Passage Configuration

We have studied the problem of light scattering in double passage configurations. Of particular interest are the mean scattered intensity and the motion of the speckle produced around the backscattering direction as the source and detector are moved. As is usual with this problem, our analysis is based on scalar wave theory and the thin phase screen model. However, with the additional assumption that the mirror is illuminated with Gaussian speckle, we obtain analytical results without further approximations. As expected, the results show that in some cases there is an enhancement in the backscattering direction. Also, in normal circumstances, the speckle pattern moves in a direction opposite to that of the source (when this is moved), and decorrelates very rapidly. However, we have found some special circumstances in which the speckle pattern seems to track the backscattering direction. This unusual behavior has been interpreted and, based on this analysis, we have proposed a new configuration for which the speckle pattern is highly symmetric and tracks the backscattering direction under very general conditions.[10]

2.8   Monostatic Bidirectional Reflectometer

During this contract period, to transfer R&D technology and innovation to military applications, we have designed, fabricated, tested and delivered a Monostatic Bidirectional Reflectometer to Eglin AFB for laser radar applications.[16]

The unique features of this instrument is listed in Table 1. This instrument not only provides field amplitudes but also phases which can account for optical phenomena such as speckle, depolarization effect and the enhanced backscattering.

Table 1
MBR Measurement Capabilities

MEASUREMENT RANGE	Measures monostatic bidirectional reflectances from 10^4 to less than 10^{-7} steradians^{-1}.		
SAMPLE ANGULAR POSITIONS	Monostatic: All positions from 0 to 75° (± 0.1°) with respect to incident beam. *Bistatic: ± 2° with respect to incident beam.*		
WAVELENGTHS, LASER AND DETECTOR TYPES	WAVELENGTH (µm)	LASER TYPE	DETECTOR TYPE
	0.6328	He-Ne	Silicon
	1.06	Nd-YAG	Silicon
	10.6	CO_2	HgCdTe
POLARIZATION COMBINATIONS	Parallel - Parallel; Parallel - Perpendicular; Perpendicular - Perpendicular; Perpendicular - Parallel		
ANGULAR RESOLUTION	Limited only by excursions of local oscillator mirror is 0.04°.		
SIGNAL OUTPUT FREQUENCY	Approximately 1K Hz (samples translated at about 500 fringes/second) Doppler frequency which prevents background noise from suspending dust in the air.		
SIGNAL AVERAGING PERIOD (For averaging out speckle effects)	45-90 seconds, with speckle mapping and histogram		

2.9   Origins of Enhanced Backscattering

What is the mechanism responsible for the enhanced backscattering? Recent simulation results have shown that for rough optical surfaces, the high-sloped nature of the surface leads to multiple scattering, and this contribution enhances the scattered light. Maradudin et al.[17] found that the enhancement was already significant in a double-scattering approximation. This was done by writing the integral equation for the surface field or its normal derivative (in the case of p- or s-polarization, respectively) for a perfectly conducting, one-dimensional random rough surface in the form of an inhomogeneous Fredholm equation of the second kind. In this equation the inhomogeneous term corresponds to the Kirchhoff, or single-scattering, approximation for the surface field, or its normal derivative, depending on the polarization. When this equation is solved iteratively, the nth term in the resulting expansion describes an n-fold scattering process. The first few terms in such a solution have been calculated and averaged with a Monte Carlo computer simulation approach. The contribution to the mean differential reflection coefficient from the incoherent component of the scattered light in the single-scattering approximation displays no enhanced backscattering; the contribution from pure double-scattering processes shows a well-defined enhanced backscattering peak. The inclusion of the contribution from triple-scattering processes modifies the sum of the other two contributions from the single- and double-scattering by only a small amount in the vicinity of the enhanced backscattering peak, and is most significant in the region of large scattering angles, where the lower order approximations reproduce the effects of shadowing poorly.

Enhanced backscattering is also predicted to occur for weak corrugations. In this case it is due to the multiple scattering of the surface polaritons excited by the incident light passing through the hills and valleys on the surface before they are converted back into volume waves in the vacuum, propagating away from the surface. The coherent interference of such a scattering sequence and its time-reversed partner leads to a two-fold enhancement of the intensity of scattering into the retroreflection direction with respect to the intensity of scattering into other directions, when the contribution from single-scattering is subtracted.[6]

3.0 LIST OF PUBLICATIONS

3.1 Publications in Journals

1. Zu-Han Gu, R.S. Dummer, A.A. Maradudin, and A.R. McGurn, "Experimental Study of the Opposition Effect in the Scattering of Light from a Random/ly Rough Metal Surface", Applied Optics, Vol. 28, No.3, 537-543 (1989).

2. Zu-Han Gu, R.S. Dummer, A.A. Maradudin, and A.R. McGurn,"Opposition Effect from Rough Metal Surface", SPIE Proceedings 1165, 42-51 (1989).

3. Zu-Han Gu and R.S. Dummer, "Small Angle Bidirectional Reflectance Distribution Function", Applied Optics 29, 4176-4181 (1990).

4. E.R. Mendez, M.A. Ponce, and V. Ruiz, "Light Scattering from One-Dimensional Surfaces with an Even Profile", SPIE Proceedings 1331, 18-29 (1990).

5. Zu-Han Gu, R.S. Dummer, A.A. Maradudin, J.Q. Lu, A.R. McGurn, and E.R. Mendez, "Experimental Study of Enhanced Transmission Through Rough Metal Surfaces", SPIE Proceedings 1331, 36-45 (1990).

6. E.R. Mendez, M.A. Ponce, V. Ruiz-Cortes, and Zu-Han Gu, "Coherent Effects in the Scattering of Light from Random Surfaces with Symmetry", Optics Letters 16, 123-125 (1991).

7. V. Celli, P. Tran, A.A. Maradudin, J.Q. Lu, T. Michel, and Zu-Han Gu, "Waves on Corrugated Surfaces: K-Gaps and Enhanced Backscattering", *Laser Optics of Condensed Matter* Vol. 2, Edited E. Garmire, A.A. Maradudin, and K.K. Refane, Plenum Publishing Corporation, New York (1991).

8. Zu-Han Gu, A.A. Maradudin, E.R. Mendez, M.A. Ponce and V. Ruiz-Cortes, "Enhanced Transmission Through Randomly Rough Surfaces", Waves in Random Media, 3, S75-S90 (1991).

9. A.A. Maradudin, J.Q. Lu, T. Michel, Zu-Han Gu, J.C. Dainty, A.J. Sant, E.R. Mendez, and M. Nieto-Vesperinas, "Enhanced Backscattering and Transmission of Light from Random Surfaces on Semi-infinite Substrates and Thin Films", Waves in Random Media, 3, S129-S141 (1991).

10. Zu-Han Gu, R.S. Dummer, A.A. Maradudin, and A.R. McGurn, "Enhanced Transmission Through Rough-Metal Surfaces", Applied Optics, Vol. 30, No. 28, 4094-4102 (1991).

11. E.R. Mendez, M.A. Ponce, V. Ruiz-Cortes, and Zu-Han Gu, "Photofabrication of One-Dimensional Rough Surfaces for Light-Scattering Experiments", Applied Optics, Vol. 30, No. 28, 4103-4112 (1991).

12. Zu-Han Gu, J.Q. Lu, A.A. Maradudin, and E.R. Mendez, "Coherence in Single and Multiple Scattering of Light from Randomly Rough Surfaces", SPIE Proceeding 1530, 60-70 (1991).

13. V. Ruiz-Cortes and E.R. Mendez, "Light Scattering from Gold-Coated Ground Glass and Chemically Etched Surfaces", SPIE Proceeding 1558, 222-232 (1991).

14. Zu-Han Gu, H.M. Escamilla, E.R. Mendez, A.A. Maradudin, T. Michel, and M. Nieto-Vesperinas, "Interaction of Two Optical Beams at a Symmetric Random Surface", Applied Optics, Vol. 31, No. 27, 5878-5889 (1992).

15. A.A. Maradudin, J.Q. Lu, P. Tran, R.F. Walls, V. Celli, Zu-Han Gu, A.R. McGurn, E.R. Mendez, T. Michel, M. Nieto-Vesperinas, J.C. Dainty, and A.J. Sant, "Enhanced Backscattering from One- and Two- Dimensional Random Surfaces", Revista Mexicana de Fisica 38, No. 3, 343-397 (1992).

16. Jeff Estep and Zu-Han Gu, "Ladar Signature Simulation", SPIE Proceeding 1700, 119-130 (1992).

3.2   Papers in Press for Publication

17. Zu-Han Gu, Z.Q. Lin, and Jeff Estep, "Calculation of Signal-to-Noise Ratio of a Monostatic Bidirectional Laser Reflectometer", accepted for publication in SPIE 1753-59, (1993).

18. Zu-Han Gu, J.Q. Lu, A.A. Maradudin, E.R. Mendez, and A. Martinez, "Coherence in Single and Multiple Scattering of Light from Randomly Rough Surfaces", accepted for publication in Applied Optics (1993).

3.3   Papers Submitted to Journal under Referee

19. E.R. Mendez, H.M. Escamilla, and D.F. Hotz, "Enhanced Backscattering of Light from a Random Rough Surface Nearly Perpendicular to a Mirror", submitted to Optical Communication (1992).

20. H.M. Escamilla, E.R. Mendez, and D.F. Hotz, "Light Scattering and Speckle in Folded Path Propagation Problems", submitted to Applied Optics (1992).

21. Zu-Han Gu, J.Q. Lu, and A.A. Maradudin, "Enhanced Backscattering of Light from a Rough Dielectric Film on a Glass Substrate", submitted to JOSA-A (1992).

3.4   Papers Presented at Professional Conferences

1. Zu-Han Gu and R.S. Dummer, "Experimental Research of Enhanced Backscattering at Surface Optics Corporation", presented at ARO sponsored International Workshop on "Enhanced Backscattering", Boston (1989).

2.   Zu-Han Gu, R.S. Dummer, A.A. Maradudin, and A.R. McGurn, "Opposition Effect from a Rough Metal Surface", presented at SPIE Annual Meeting, San Diego (1989).

3.   Zu-Han Gu, "Recent Advances in the Experimental Study of Enhanced Backscattering", presented at the workshop on "Enhanced Backscattering in Reflection", U.C. Irvine, (December 1989).

4.   Zu-Han Gu, E.R. Mendez, and A.A. Maradudin, "Enhanced Transmission through Rough Metal Surfaces", presented at American Physical Society Annual Meeting, Anaheim (March 1990).

5.   Zu-Han Gu, R.S. Dummer, A.A. Maradudin, J.Q. Lu, A.R. McGurn, and E.R. Mendez, "Experimental Study of Enhanced Transmission through Rough Metal Surfaces", presented at SPIE Annual Meeting, San Diego (July 1990).

6.   E.R. Mendez, M.A. Ponce, and V. Ruiz, "Light Scattering from One-Dimensional Surfaces with an Even Profile", presented at SPIE Annual Meeting, San Diego (July 1990).

7.   Zu-Han Gu, A.A. Maradudin, E.R. Mendez, M.A. Ponce, and V. Ruiz-Cortes, "Enhanced Transmission through Randomly Rough Surfaces", presented at ARO sponsored International Workshop on "Modern Analysis of Scattering Phenomena", Aix en Provence, France (September 1990).

8.   A.A. Maradudin, J.Q. Lu, T. Michel, Zu-Han Gu, J.C. Dainty, A.J. Sant, E.R. Mendez, and M. Nieto-Vesperinas, "Enhanced Backscattering and Transmission of Light from Random Surfaces on Semi-infinite Substrates and Thin Films", presented at ARO sponsored International Workshop on "Modern Analysis of Scattering Phenomena", Aix en Provence, France (September 1990).

9.   Zu-Han Gu, R.S. Dummer, A.A. Maradudin, and E.R. Mendez, "Enhanced Transmission through Rough Surfaces with an Even Profile", presented at OSA 1990 Annual Meeting, Boston (November 1990).

10.   M.A. Ponce, E.R. Mendez, and V. Ruiz, "Scattering from Symmetric Surfaces and Surfaces Perpendicular to a Mirror", presented at OSA 1990 Annual Meeting, Boston (November 1990).

11.   J.Q. Lu, and A.A. Maradudin, "Enhanced Backscattering of Light from Random Nonlinear Surfaces", presented at PIES, Boston (July 1-5, 1991).

12.   Zu-Han Gu, A.A. Maradudin, and E.R. Mendez, "Coherence in Single and Multiple Scattering of Light from Randomly Rough Surfaces", presented at PIES, Boston (July 1-5, 1991).

13.   E.R. Mendez, V. Ruiz-Cortes, M.A. Ponce, A.A. Ponce, A.A. Maradudin, J.Q. Lu, and Zu-Han Gu, "Light Scattering from Fabricated Random Surface with Non-Gaussian Statistics", presented at PIES, Boston (July 1-5, 1991).

14.   Zu-Han Gu, A.A. Maradudin, and E.R. Mendez, "Coherence in Single and Multiple Scattering of Light from Randomly Rough Surfaces", presented at SPIE Annual Meeting, San Diego (July 24-26, 1991).

15.   Zu-Han Gu and R.S. Dummer, "Small Angle Scattering Measurement", presented at SPIE Annual Meeting, San Diego (July 24-26, 1991).

16. V. Ruiz-Cortes, E.R. Mendez, Zu-Han Gu, and A.A. Maradudin, "Light Scattering from Gold-Coated Ground Glass and Chemically Etched Surfaces", presented at SPIE Annual Meeting, San Diego (July 24-26, 1991).

17. Zu-Han Gu, R.S. Dummer, J.C. Jafolla, A.A. Maradudin, "Enhanced Backscattering in Laser Radar Signatures", presented at ICO topical meetings on "Atmospheric, Volume and Surface Scattering and Propagation", Florence, Italy (August 27-30, 1991).

18. E.R. Mendez, H.M. Escamilla, and Zu-Han Gu, "Light Scattering and Speckle in Folded Path Propagation Problems", presented at ICO topical meetings on "Atmospheric, Volume and Surface Scattering and Propagation", Florence, Italy (August 27-30, 1991).

19. Jeff Estep and Zu-Han Gu, "Ladar Signature Simulation", presented at SPIE Orlando, FL Meeting (April 1992).

20. Zu-Han Gu, R.S. Dummer, H.M. Escamilla, E.R. Mendez, A.A. Maradudin, J.Q. Lu, T. Michel, and M. Nieto-Vesperinas, "Interaction of Two Optical Beams at a Symmetric Random Surface", presented at OSA topical meeting on "Surface Roughness and Scattering", Tucson (June 1992).

21. Zu-Han Gu, "Recent Experimental Studies of Enhanced Backscattering from Rough Surfaces", presented at U.C. Irvine Workshop on "Enhanced Backscattering of Light from Randomly Rough Surfaces, and Related Phenomena", Irvine (June 1992).

22. Zu-Han Gu, Z.Q. Lin, and Jeff Estep, "Calculation of Signal-to-Noise Ratio of a Monostatic Bidirectional Laser Reflectometer", presented at SPIE Annual Meeting, San Diego (July 1992).

23. Zu-Han Gu, R.S. Dummer, H.M. Escamilla, E.R. Mendez, A.A. Maradudin, J.Q. Lu, T. Michel, and M. Nieto-Vesperinas, "Interaction of Two Optical Beams at a Symmetric Random Surface", presented at OSA Annual meeting, Albuquerque (September 1992).

24. Zu-Han Gu, E.R. Mendez, and A.A. Maradudin, "Enhanced Backscattering from a Character-ized Dielectric Random Surface", presented at OSA Annual meeting, Albuquerque, NM (September 1992).

4.0 LIST OF ALL PARTICIPATING SCIENTIFIC PERSONNEL

NAME	TITLE	COMPANY
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